magnitudes $|\eta_{00}/\eta_{+-}|$ is largely independent of the dilution factor. We find $\varphi_{00}-\varphi_{+-}=12.6°\pm 6.2°$ and $|\eta_{00}/\eta_{+-}|=1.00\pm 0.09$.[6]

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Measurement of the Phase and Magnitude of η_{+-}

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The phase and magnitude of the *CP*-nonconservation parameter η_{+-} have been determined from the proper-time distribution of $K^0\to\pi^+\pi^-$ decays in a short-lived neutral beam. We find $\varphi_{+-}=41.7°\pm3.5°$ and $|\eta_{+-}|=(2.27\pm0.12)\times10^{-3}$.

The measurement of φ_{00} and $|\eta_{00}|$ reported in the preceding Letter[1] required a detailed understanding of the short-lived neutral beam and of the properties of the experimental apparatus. Our study of $K^0\to\pi^+\pi^-$ decays in the same apparatus used in the $2\pi^0$ experiment has resulted in values of φ_{+-} and $|\eta_{+-}|$ in agreement with previous experiments, lending confidence in our ability to measure these sensitive parameters accurately and without bias. The large number of $\pi^+\pi^-$ decays probe features common to the two experiments but not visible in the less well-resolved $2\pi^0$ data. The crucial comparison of the phase and magnitude of η_{00} and η_{+-} is better made in a single experiment under the same conditions and free of common systematic errors.

The experimental arrangement is shown in the preceding Letter.[1] The event trigger required that charged particles pass through the spectrometer, one on each side of the beam, producing exactly two hits in each of the ten proportional wire chambers (PWC's). Triggers from the copious $\Lambda^0\to\pi^-p$ decays were reduced by means of a small scintillation counter positioned near the beam to catch the forward high-momentum proton characteristic of these decays. Most events containing muons were removed by a plane of counters placed behind 4 ft of steel at the rear of the apparatus.

Three-quarters of the triggers were found to contain two complete particle trajectories emanating from a well-defined vertex. All spatial distributions and resolution functions were described in detail by a Monte Carlo simulation. The complete two-body mass spectrum, including both inbending and outbending events, is shown in Fig. 1(a). A sample of inbending $\pi^+\pi^-$ data with proper time $\tau\sim 9\tau_S$ (τ_S is the K_S lifetime) is shown in Fig. 1(b). The mass of a $K^0\to\pi^+\pi^-$ decay was measured to 9 MeV/c (1 standard deviation) and the kaon direction was determined to 2 mrad. The full data sample includes 900 000 inbending $\pi^+\pi^-$ decays with momenta between 6 and 16 GeV/c, covering the proper-time range $4\tau_S<\tau<18\tau_S$. About 540 000 events were recorded with the apparatus in its most forward position while 360 000 events were accumulated with the apparatus rolled 40 in. downstream.

Lambda decays were easily identified because the positively charged secondary (the proton) had a momentum at least three times that of the negatively charged particle; events whose π-p effective mass fell within 15 MeV of the lambda mass were removed. The three-body decays $K^0\to\pi^+\pi^-\pi^0$

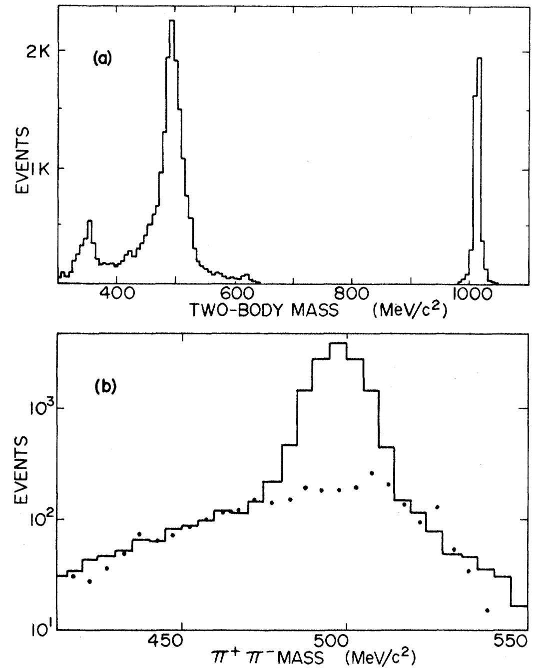

FIG. 1. (a) Reconstructed two-body mass spectrum. Events in the Λ° peak have been scaled down by a factor of 4. (b) $\pi^+\pi^-$ mass distribution for events with proper times near $9\tau_S$. The solid dots represent the estimated background.

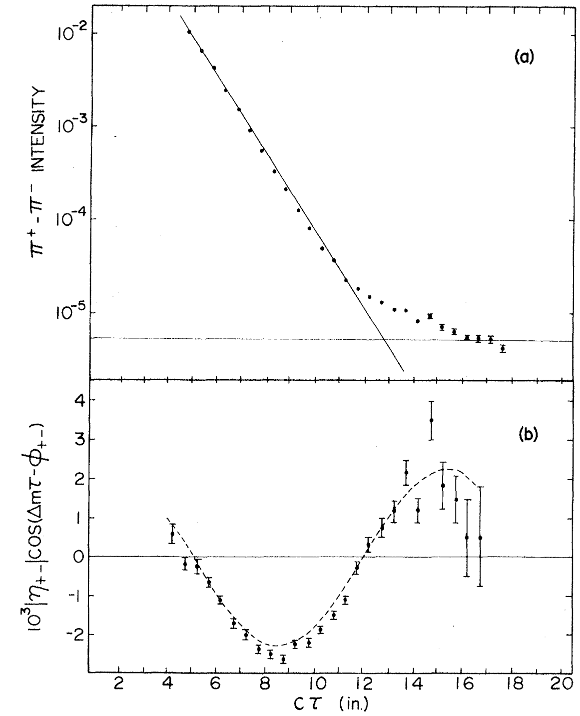

FIG. 2. (a) Efficiency corrected data. The lines represent the squared terms in Eq. (1): $\exp(-\tau/\tau_S)$ and $|\eta_{+-}|^2$. (b) CP-nonconserving interference extracted from the data. The smooth curve is $|\eta_{+-}|\cos(\Delta m\,\tau - \varphi_{+-})$ with use of the best-fit parameters for φ_{+-} and $|\eta_{+-}|$.

were resolved from the two-body events since the effective mass of the $\pi^+\pi^-$ system cannot exceed 360 MeV. Because lead-glass pulse heights were not recorded for most of the data, electrons could not be identified and were mislabeled as pions. However, the resulting background was studied in detail with a sample of events containing the full lead-glass information. The background was found to be dominated by K_{e3} decays, with a residual $K_{\mu 3}$ component and a small contamination of events from neutron interactions in the helium-filled decay region. A Monte Carlo simulation accurately described the K_{e3} background as a function of the kaon momentum (P) and length of flight (Z), and was used to remove the background from the data. This background varied from less than 1% at small proper times to 50% at very large times. A typical mass spectrum of the data and of the estimated background is presented in Fig. 1(b).

The background subtracted data were corrected for the detection efficiency of the spectrometer. The events in each 0.5 GeV/c by 5 in. (P, Z) bin were normalized to the total number of events at that momentum, as in the $2\pi^0$ analysis. The resulting distribution in proper time is shown in Fig. 2(a). The $\pi^+\pi^-$ intensity was fitted with the function

$$I = \exp(-\tau/\tau_S) + |\eta_{+-}|^2 + 2D(P)|\eta_{+-}|\cos(\Delta m\,\tau - \varphi_{+-})\exp(-\tau/2\tau_S). \quad (1)$$

The dilution factor $D(P)$ is defined as the difference divided by the sum of K^0 and $\bar{K}^0$ intensities at the production target. As in the $2\pi^0$ experiment, a small modification was made to Eq. (1) to correct for the effects of coherent regeneration and diffraction scattering in the γ-ray filter and the wall of the collimator. With use of a value for the K_L-K_S mass difference Δm of $(\Delta m)\tau_S = 0.4774 \pm 0.0020$,[2] a three-parameter fit to the data with the apparatus in the forward position gives $\varphi_{+-} = 43.3° \pm 2.9°$, $|\eta_{+-}| = (2.27 \pm 0.07)\times 10^{-3}$, and $c\tau_S = 1.059 \pm 0.004$ in., with $\chi^2 = 390$ for 427 degrees of freedom. With the apparatus 40 in.

downstream, we find $\varphi_{+-} = 40.1° \pm 3.1°$, $|\eta_{+-}| = (2.27 \pm 0.08) \times 10^{-3}$, and $c\tau_S = 1.058 \pm 0.004$ in. with $\chi^2 = 511$ for 517 degrees of freedom. Since the detection efficiency is different for the two positions, the consistency of the two results demonstrates that the effects of the apparatus are properly accounted for, and the two sets of data may be safely combined.

Because the data extend to very large proper times, where the $|\eta_{+-}|^2$ term is substantial, the value of $|\eta_{+-}|$ extracted from the fit is insensitive to the dilution factor. The dilution factor used in the fits is $D(P) = 1 - 1.5e^{-0.17P}$. This functional form was motivated by the ratio of K^+ to K^- production at alternating-gradient synchroton (AGS) energies[3] and the coefficients fixed by fits to our data in 2-GeV/c momentum intervals 6 to 16 GeV/c.

All of the data is shown in Fig. 2(b) with exponential factors removed to exhibit the oscillatory interference term clearly.

As the momentum of the kaon decreases, the background increases and effects of the filter and collimator regeneration grow. However, the values of φ_{+-} and $|\eta_{+-}|$ remain constant as the lower momentum cut used in the fit is varied, as seen in Fig. 3. Figure 4 shows the dependence of φ_{+-} and $|\eta_{+-}|$ on the K_S lifetime. Because of the extended proper-time range of these data, $|\eta_{+-}|$ is less sensitive to the lifetime than $|\eta_{00}|$ is in the $2\pi^0$ measurement. The results of a three-parameter fit are $\varphi_{+-} = 41.7° \pm 2.1°$, $|\eta_{+-}| = (2.27 \pm 0.05) \times 10^{-3}$, and $c\tau_S = 1.059 \pm 0.003$ in. The errors are purely statistical.

Systematic uncertainties in the magnitude and phase come from errors in the measurement of P and Z. Data taken with a 4-in. lead regenerator at three positions along the beam were used to check the reconstruction of the vertex. A veto counter against the downstream face of the regenerator was used to produce a sharp onset in Z of $\pi^+\pi^-$ triggers. The reconstructed regenerator positions were within 0.25 ± 0.25 in. of their nominal values. The mean $\pi^+\pi^-$ mass in each (P, Z) bin averaged 0.8 MeV/c^2 above the Monte Carlo result, implying a momentum scale uncertainty of 0.3%. These limits on the systematic uncertainties in P and Z guarantee that the proper time is accurately determined to 0.35%. The background subtraction was systematically varied by warping it as a function of (P, Z). The dilution factor was raised and lowered by 10%. The uncertainty in the correction for regeneration and diffraction was estimated. The resultant systematic errors are $2.5°$ in φ_{+-} and 0.11×10^{-3} in $|\eta_{+-}|$. Combining these systematic errors with

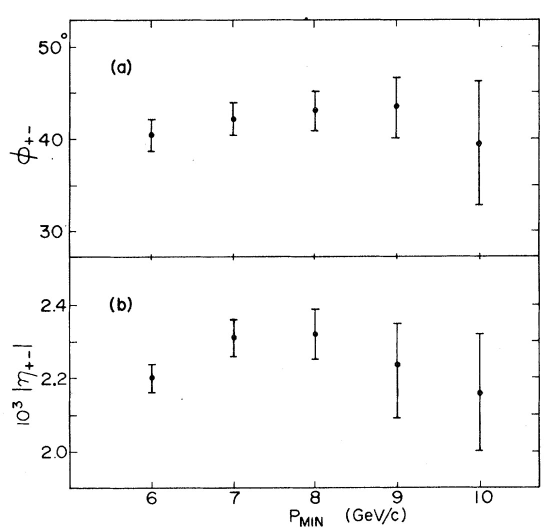

FIG. 3. φ_{+-} and $|\eta_{+-}|$ as a function of the lower bound on the kaon momentum used in the fit. The lifetime was fixed at $c\tau_S = 1.053$ in.

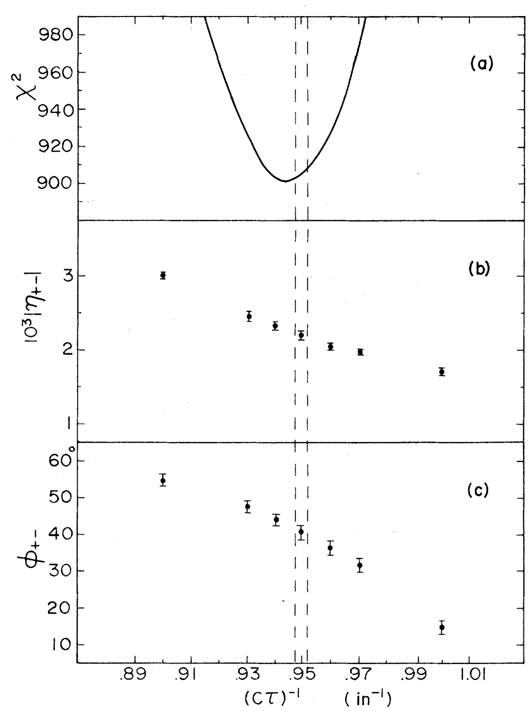

FIG. 4. Dependence of χ^2, $|\eta_{+-}|$, and φ_{+-} on the K_S lifetime. The vertical band represents ±1-standard-deviation limits from the lifetime measured in previous experiments (Ref. 2).

a 1.2° uncertainty from the measured mass difference and with the statistical uncertainties gives final results of $\varphi_{+-} = 41.7° \pm 3.5°$, $|\eta_{+-}| = (2.27 \pm 0.12) \times 10^{-3}$, and $c\tau_S = 1.059 \pm 0.008$ in. These results are in good agreement with recent measurements.[2]

For comparison with the $2\pi^0$ results, we consider only kaons with momenta above 8 GeV/c, constrain the lifetime to $c\tau_S = 1.053$ in., and remove those uncertainties common to the two measurements. For this comparison we find $\varphi_{+-} = 43.1° \pm 2.4°$ and $|\eta_{+-}| = (2.32 \pm 0.10) \times 10^{-3}$.

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Charge-Symmetry Test in the Reaction $np \to d\pi^0$

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A sensitive test of the charge symmetry of nuclear forces is the angular symmetry about 90° of deuterons produced in the $np \to d\pi^0$ reaction. We predict a front-to-back asymmetry of about 0.8% in the $\Delta(3,3)$ resonances region. The asymmetry arises primarily from π^0-η mixing.

Charge symmetry of nuclear forces, invariance under reflection about a plane perpendicular to the charge axis, predicts the equality of the *nn* and *pp* forces. To date, there is no *direct* experimental evidence against this symmetry,[1] although binding-energy differences between mirror nuclei, for example, suggest that the symmetry is broken. Coulomb and magnetic forces are unable to account for these binding-energy differences.

In addition to the equality of *nn* and *pp* forces, charge symmetry predicts the conservation of isospin for two-nucleon systems of zero charge.[2] One consequence[1,2] of isospin conservation is that the angular distribution of deuterons produced in the $np \to d\pi^0$ reaction is symmetric about 90° in the center-of-mass system. The indistinguishability of protons guarantees the symmetry in the $pp \to d\pi^+$ reaction. If isospin is conserved in the $np \to d\pi^0$ reaction, the initial *np* state must have isospin 1, and the 90° symmetry is again obtained.

Since the angular asymmetry involves transitions between states of different isospin, it is a phenomenon different from the more often considered comparison of *nn* and *pp* scattering. It depends on class-IV forces rather than class-III forces, in the nomenclature of Ref. 1. Tests of class-IV forces in elastic *np* scattering have also been recently examined.[3]

In the present note, we calculate the angular asymmetry to be expected in the energy region of the $\Delta(3,3)$ resonance for the $np \to d\pi^0$ reaction and show that the effect should be observable with only a modest increase in experimental ac-

